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Ultradian Rhythms in Prolonged Human Performance

Peretz Lavie, Jacob Zomer, and Daniel Gopher
Institute of Technology
Haifa, Israel

for

Contracting Officer's Representative
George W. Lawton

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Lavie, Peretz; Zomer, Jacob; and Gopher, Daniel

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Department of Behavioral Biology
Faculty of Medicine, Technician
Haifa, Israel

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13. ABSTRACT (Maximum 200 words)

This study investigates (1) the occurrence of approximately 14.4 cycles/day ultradian rhythms in the ability to fall asleep during morning and afternoon hours, (2) the phase relationship between these rhythms and the REM-NONREM sleep state rhythms, and (3) the phase relationship between the sleepiness rhythms and ultradian rhythms in perceptual motor performance. Eight healthy males ages 24 ± 2 with normal sleep-wake habits were tested. Each subject, after an adaptation night, spent two 24-hour periods in the laboratory. Subjects began at 1600 a strict 5:15 min sleep-wake schedule that lasted for 8 hours (1600-2400). During each of the 24 5-min sleep attempts, polysomnographic recordings were done and during the 15-min scheduled wake time psychomotor testings were conducted. At 2400 subjects retired for an uninterrupted nocturnal sleep with polysomnographic recordings. Subjects were awakened after 6-7 hours of sleep and a second 8-hour period of the same schedule was initiated. Awakening from nocturnal sleep was timed by the experimentor either from REM sleep (first 24-hr experimental period) or about 25 min after the end of a REM period (second experimental period) for 4 subjects, and the reverse order for
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13. ABSTRACT (Continued)

the other 4 subjects. Although the average percentages were similar, spectral analysis revealed a different temporal structure of stage 1 and 2. Distributions were bimodal with peaks around 1630 and 2300. The morning distributions were much more episodic, resembling the 90-min ultradian rhythmicity reported by Lavie and Scheron (1981). These results suggest that, in spite of the impressive stability of the morning and evening (accumulated) sleep, the ultradian rhythmicity in sleepiness is nonstationary and is modulated by a circadian cycle.

Ultradian rhythms of similar frequency were found in perceptual and motor performance. The rhythms in perception, however, were drastically modified by altering the sampling frequency and were, therefore, attributed to statistical artifact. The rhythms in motor performance, on the other hand, persisted under both sampling frequencies and can therefore be considered a true endogenous rhythmicity. The analysis of the phase relationship between the rhythms in motor performance and physiological indexes of arousal is being performed in our laboratory.

Introduction

The recent wave of interest in rhythms in human behavior is erroneously attributed to the recent developments in the study of biological rhythms. In a recent historical review of the field of behavioral rhythmic research Lavie (1980a) uncovered several independent roots of research unrelated to questions regarding the nature and functions of biological rhythms. One of these roots was the rather naive ambition of educational psychologists to schedule school hours according with the optimal times for cognitive functioning such as mathematics, reading, etc, on the one hand, and activities requiring psychomotor skills, on the other. This research which attracted quite a number of investigators around the turn of the century, died away around the mid 1920's. Recently it has been revived by the renewed interest in biological rhythms, sleep rhythms, and their interaction with behavior.

The notion of an optimal schedule of human behavior is indeed an attractive one. In nature, optimal scheduling and synchronization of different behaviors with the geophysical environment is for many species a crucial survival issue. Displaying courting behavior at the wrong times of the year is dangerously maladaptive, while synchronization of courting and mating behavior with suitable environmental conditions ensures offspring survival.

Although human behavior is much more flexible and considerably less dependent on environmental conditions, questions regarding the influence of biological rhythms on human behavior, and consequently the possibility of optimizing human behavior by accurate scheduling and synchronizing behaviors with known biorhythms has been recently repeatedly raised. Such possibilities have been discussed in the context of shift work schedules, work-rest schedules, mental illness, sleep deprivation

procedures and its influence on behavior, jet lag, space missions and living in time free environments. The great interest in these questions is attested by the large number of symposia and scientific publications dedicated to these subjects appearing in the last decade (e.g. Colquhoun, 1971; Moses et al, 1978; Lavie, 1980b)

While the major bulk of this research has focused on circadian rhythms, that is, rhythms of approximately 24 hours, in our laboratory in the last three years we have studied much faster rhythms of about 90-100 min/cycle (ultradian rhythms). Though it is beyond the scope of this report to summarize all the accumulated data on ultradian rhythms (for a recent comprehensive review of this area see Lavie, 1980b), a brief outline of these findings seems in order before we describe and discuss our research for 1979/80.

Evidence for the existence of a short term periodicity in the activity of the central nervous system can be traced back to the beginning of the century. Wada, for instance, (1922) observed a 40-45 min activity cycle in infants, which she associated with periodic gastric contractions. Wada also noted similar gastric episodes in adults, both during the waking and sleep states, but at intervals of one and a half to two hours. Until the sixties these findings were considered, at the most, as anecdotal data, or as noise in the results, and no attempt was made to explore further the possibility of the existence of ultradian rhythms in the functioning of the nervous system. The discovery of the REM-NONREM cycle by Aserinsky and Kleitman (1953) signaled the turning point in the understanding of the sleep process, and paved the way to the acceptance of the ultradian notion.

Kleitman (1961) intuitively speculated on the existence of short term periodicity in the functioning of the nervous system, for which he

coined the name: Basic Rest-Activity Cycle (BRAC). According to Kleitman, this cycle originates as a primitive sleep and waking cycle which is adjusted to the organism's nutritional needs, and is essentially a gastric cycle mediated by humoral agents or hunger contractions. Advanced types of sleep and wakefulness develop as the organism matures, and the basic periodicity appears in the alternation between REM sleep and NONREM sleep. Besides its manifestation as the REM-NONREM cycle, Kleitman suggested that the Basic-Rest Activity Cycle may also manifest itself in the (matured) wakefulness phase as recurrent fluctuations in alertness.

Evidence for the existence of the approximate 80-100 min periodicity during wakefulness and sleep have been accumulated in recent years. Surprisingly, however, although Kleitman's proposed BRAC model has been generally confirmed, the accumulated data suggest that 90 min rhythmicity in alertness is only one of several wake and sleep rhythmicities, all sharing the same basic periodicity of approximately 80-100 min. There are accumulated evidence for the existence of 80-100 min rhythmicities in four different physiologic and psychologic processes related to a) alertness, b) performance, c) body fluid and electrolyte balance, and d) gastric motility. Only rhythm processes in alertness and performance are relevant to the present experiment.

<u>Alertness</u> - In isolated subjects under partial sensory deprivation, Kripke (1972) reported significant rhythms of 10-20 cycles/24 hours in electroencephalographic activity at various frequencies that were most prominent in the delta frequency band ($\frac{1}{2}$-3 Hz). Later Kripke and Sonnenschein (1978) investigated the relations between waking rapid eye movements electroencephalographic activity and daydreaming in isolated subjects. They reported that vivid daydreaming, resembling the

hypnagogic hallucinations of sleep onset, occurred at 90 min intervals
and were correlated with increased intensity of EEG alpha activity and
dimunition of rapid eye movements. Cyclic changes in rapid eye movement
activity in waking humans were reported also by Othmer et al (1969).

Pupillary diameter, stability and reactivity to light are well
established physiologic indices of sleepiness and fatigue. Recently
Lavie (1979) showed ultradian variations in pupillary size and pupillary
stability under constant illumination conditions. The rhythms in pupillary
diameter and in the index of pupillary stability were 180° out of phase
with each other. This is, pupillary dilation was associated with increased
stability of pupillary diameter. In the second year of our 3 year
experimental program (Lavie & Scherson, 1981), we demonstrated that the ultradian
rhythms in alertness is manifested in rhythmic tendency to fall asleep
during the day. We assumed that if ultradian rhythms in alertness exist,
they should be manifested in the ability to fall asleep at different times
during the day. We showed that subjects attempting to fall asleep every
20 min for 5 min, revealed significant ultradian rhythmicity in the
appearance of sleep stage 1. Under total and selective REM sleep
deprivation conditions, however, much slower rhythmicity appeared. A
similar experimental approach was utilized in the present experiments
to determine the relationship between performance and alertness.

Performance - Though it would be logical to look for rhythms in
vigilance in the light of the BRAC hypothesis, there has been surprisingly
little work in this direction. Globus et al (1971) reported equivocal
100 minute cycles in performance of a 6 hour continuous vigilance task.
However, these rhythms were rather weak and accounted for negligible
portion of the total variability. Orr, Hoffman and Hegge (1974) studied

prolonged complex vigilance and concomitantly monitored heart rate. Complex demodulation revealed a 90 minute periodicity in performance, which was weakly and inconsistently related to changes in heart rate. The statistical technique however did not permit evaluation of the statistical significance of the performance rhythms.

In the first and second years of our 3 year experimental program we have employed perceptual-motor rather than vigilance tasks because the former are more easily controlled and can be administered for brief periods spread out over many hours, preventing the confounding of possible ultradian rhythms with fatigue effects which occur in continuous vigilance tasks.

We first investigated the linear positioning task (Lavie, Gopher, Fogel and Zommer, 1979), in which subjects were required to move a lever to a distance of 30 cm along a metal rod, relying only on auditory and pro-prioceptive stimuli. The results demonstrated that positioning errors in the NKR condition varied in a 90 minute ultradian rhythm. The rhythms were of large amplitude and accounted for approximately 20% of the variance, but in some subjects as much as 30% of the total variance was accounted by ultradian rhythmicity. No significant periodicity was found in speed of performance in either condition, and no rhythms in accuracy were found in the KR "feedback" condition. Between trials urine volume was also sampled. This varied in an ultradian rhythm, but these cycles were not consistently related to performance rhythms (Gopher and Lavie, in press)

Though the positioning task did not reveal cyclic changes in movement time, we hoped that such rhythms in reaction time might be evident in another type of task. In that study (Lavie, Gopher, Zohar and Gonen, 1978), an adaptive serial reaction time test was used, subjects responded to random numbers appearing on a CRT by pressing the appropriate button

before display termination; failures to respond before termination of the display and incorrect responses were scored as errors. Spectral analyses of mean and modal display times in each session revealed no significant ultradian performance rhythms in either day or night sessions.

Most recently, Klein and Armitage (1979) tested Broughton's (1975) idea that the BRAC involves an alternation in the relative efficiency of the two cerebral hemispheres, and reported 180° out of phase 100 min oscillations in a verbal and a spatial matching task, supporting Broughton's hypothesis. Their results were also investigated in the present experiments.

The purpose of the present experiments were two: 1) to determine the possible phase relationships between the sleep REM-NONREM cycle and the ultradian sleepiness rhythms, 2) to determine the possible relationship between the ultradian sleepiness rhythms and the ultradian rhythms in positioning performance and cognitive asymmetry. Several papers are currently being prepared from these studies, the present technical report describes the main findings.

Method & Materials

Subjects

Eight healthy, right-handed males, aged 24±2 participated in the study. All were active veterans of the IDF in combat units. Subjects were well trained on the experimental tasks and were adapted to the experimental sleep laboratory conditions before the beginning of the study.

Design

Each subject was tested twice, each time for a period of approximately 24 continuous hours.

All experiments began at 1600;
subjects came to laboratory an hour before the beginning of the study and
were fitted with electrodes to monitor their EEG, EOG and EMG. At 1600
they were placed on a 15 min wake - 5 min sleep schedule which lasted for
8 hours until 2400. Each "sleep attempt" was monitored polygraphically.
Recordings were done in a darkened, semi-soundproof room, and subjects
were required to close their eyes and attempt to fall asleep.

Performance measurements were taken during the 15 min scheduled wake
periods. In four subjects (Group 1), dot localization was measured every
10 min, just before the 20 min sleep attempt and immediately after that,
and linear positioning was measured every 20 min at about the middle of
the 15 min wake period. The four other subjects (Group 2) were tested
in the reverse order, every 10 min on the linear positioning and every
20 min on the dot localization test. Light snacks and soft drinks were
available ad libitum and no attempt was made to isolate subjects from
external time cues.

A monitored sleep period in the laboratory beginning at 2400,
followed the 8 hour experimental period. The sleep period was ter-
minated either 15 min after the beginning of the first REM period
appearing between 0500 and 0700, or 35 min after the end of that REM
period in sleep stage 2. A second 8 hour experimental period, similar
to the 1600-2400 testing period was begun immediately after the
awakening. The order of awakenings either from REM or NONREM was
counterbalanced across subjects.

Statistical Analysis

For each subject and for each 8 hour testing period, 24-point or
48-point time series were constructed from: 1) the percent stage 1 in

each 5 min sleep attempt, 2) percent stage 2, 3) linear positioning (NKR), and 4) dot localization. Then spectral analysis was performed as described in our previous technical reports (see Lavie, Gopher, Zohar & Gonen, 1978).

Since the 5 min sleep attempts could affect the rhythmicity in performance, separate analysis was performed for tests performed just before and immediately after the 5 min "sleep attempt".

Phase Relationship Between Sleepiness and Performance

Pearson product moment correlation coefficients were calculated between percentages of sleep stage 1 and performance measurements. Since we were particularly interested in the temporal structure of the covariations in sleepiness and performance, hanned spectra, coherence spectra and cross spectral phase-angle-differences will be calculated at each spectral frequency between the sleepiness measures and linear positioning performance, and localization performance. However, since these analyses are time consuming and require a considerable amount of computer time, they are still in progress and are not included in the present technical report. A separate report will be prepared on the cross spectral phase-angle differences between the physiologic and behavioral measurements.

Results

% Total Sleep

Fig. 1A,B,C presents the percentage of total sleep in each of the 5 min sleep attempts averaged across all 8 subjects for the two morning experiments. Except for an initial phase difference, the average curves are similar with sleepiness peaks appearing at similar times after the awakening. When awakened from NONREM sleep, however, subjects had during
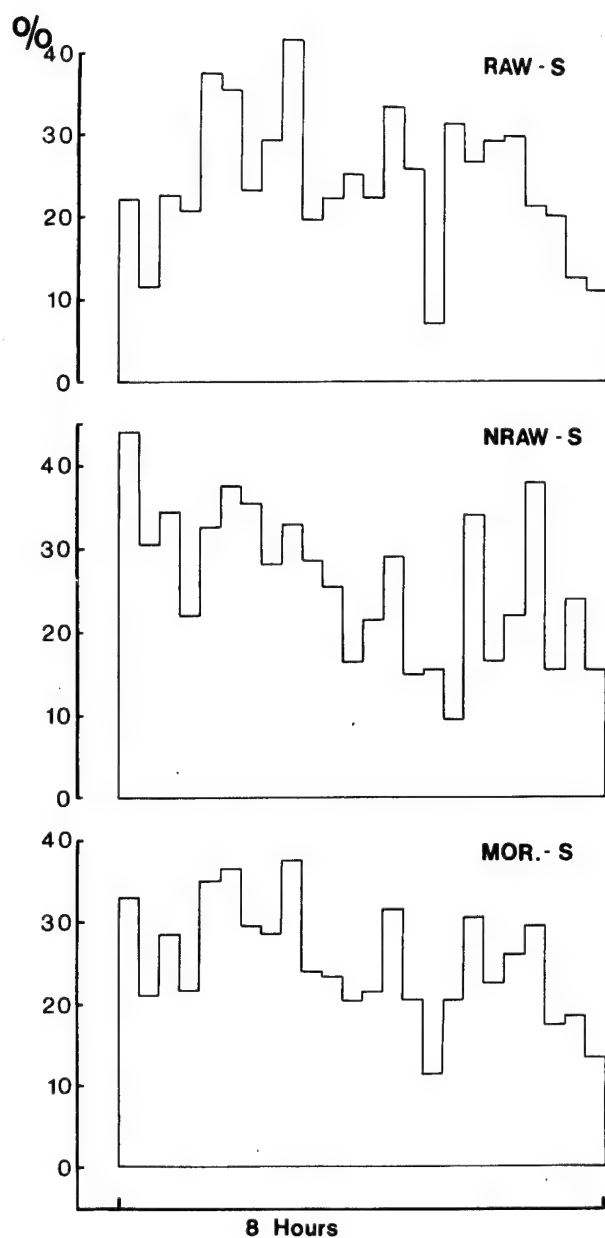
Fig. 1 A, B, and C. Percentages of total sleep for REM awakening, NONREM awakening, and for all mornings.

the first 3 sleep attempts considerably higher sleep percentages (44 vs. 21.9, 30.6 vs. 11.3, and 34.4 vs. 22.5). Since, however, only six of the 8 subjects showed this difference, it only bordered statistical significance. In spite of this initial difference, the first post-awakening sleepiness peak appeared at approximately the same time, 100-120 min from the beginning of the experiment. Consequently, cross-spectral phase angle (5 frequencies) between the two average curves at the expected 14.4 c/d ultradian frequency was small, 43°.

Fig. 2 presents the average sleepiness curve for all the afternoon experiments (N=16). In marked difference from the morning pattern, the curve is clearly quadratic and considerably less episodic, with initial sleepiness peak around 1640 and 1800 and a late sleepiness peak at 2240-2400; the quadratic trend is clearly emphasized by smoothing the average curve (see Fig. 2). Similar pattern is seen when data of the first day and second day are averaged separately.

% Stage 1

Total sleep is composed of stage 1 and stage 2 and negligible amounts of sleep stage 3-4. Since our previous studies (Lavie & Scherson, 1981) demonstrated different temporal structure for stage 1 and stage 2, the distributions of the two sleep stages were analyzed separately. Fig. 3 A, B, & C presents the average curves for stage 1 for REM (N=8) and NONREM (N=8) awakenings. The average curves are remarkably similar. Stage 1 peaked at the 5th session and at the 18th-19th session, that is, 100 min and 360-380 min after the awakenings. The similarity in the temporal structure between the conditions was reflected in a positive pearson linear cor-relation between the average curves (r=.37). There was no difference in
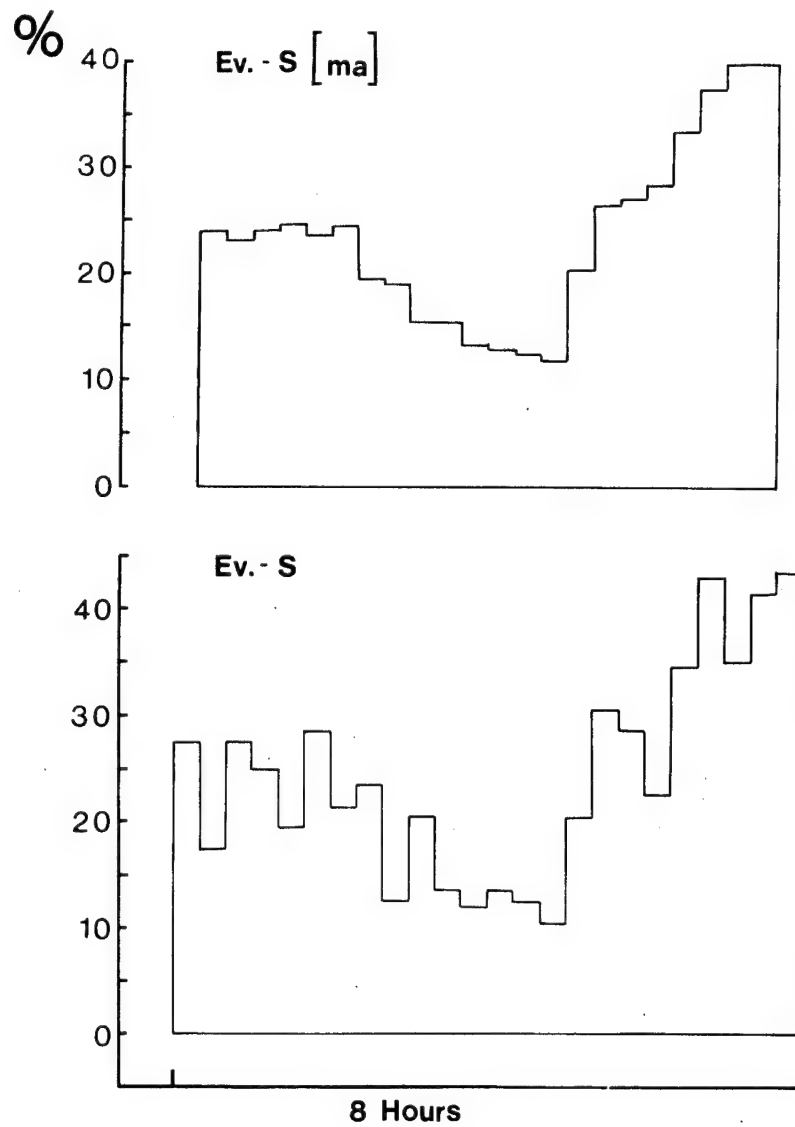
Fig. 2 Percentages of total sleep for all morning
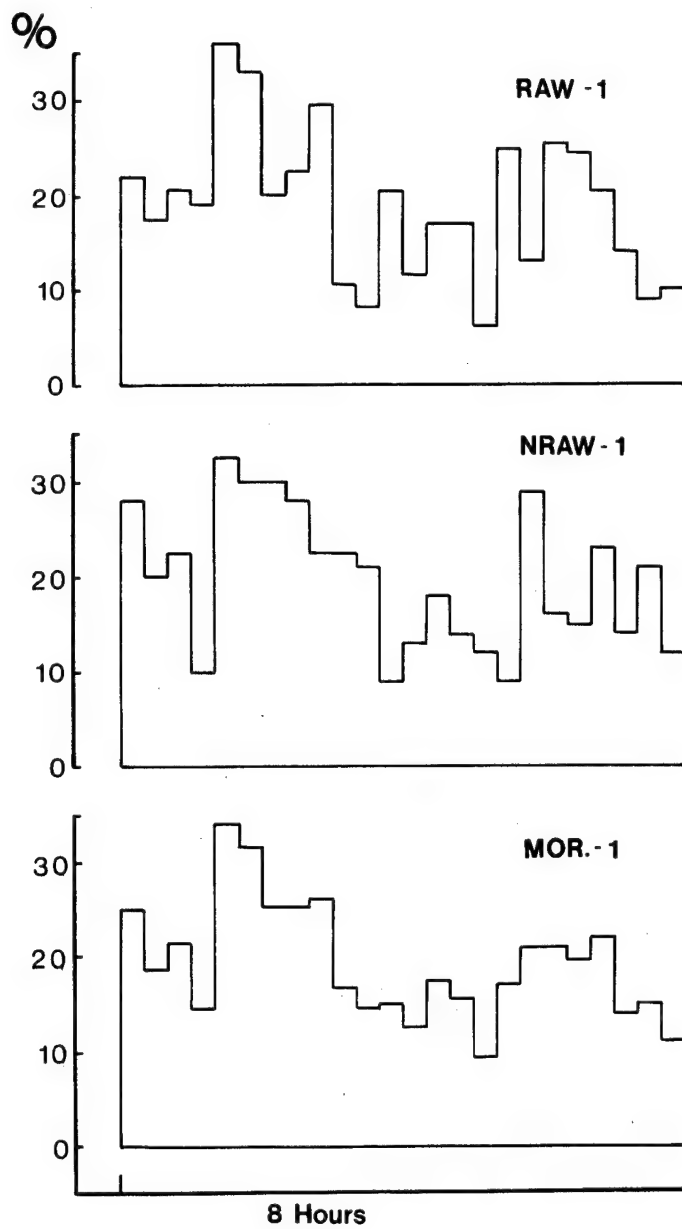experiments (Ev-s), and the smoothed curve (Ev-s ma)

Fig 3 A, B, and C. Percentages of sleep stage 1 for
REM awakening, NONREM awakening, and for all mornings.

the average percentages of stage 1 (18.7% ± 7.9% and 19.3% ± 7.5%) between

the post-REM and post-NONREM conditions. The general structure appears

quadratic with some episodes of increased stage 1 superimposed; this

structure is further emphasized in the average curve based on both REM

and NONREM awakenings (N=16). The evening curve for stage 1 (Fig. 4 upp. pannel)

(N=16) is also quadratic with peaks of stage 1 occurring at 1720 and 2300.

The average percentage of sleep stage 1 during the afternoon was 14.8% ±

5.1%.

% Stage 2

Fig 5 AB C   presents the average curves for the percentages of sleep

stage 2 in each of the experimental sessions for the REM and NONREM

conditions. Except for the initial two hours, where a large difference

exists in occurrence of sleep stage 2, the two curves appear remarkably

similar with episodic occurrence of sleep stage 2 occurring at about the

same times after the awakenings regardless of the awakening condition.

Consequently, the average curve based on all the morning time series is

clearly episodic, with 4 episodes (at the 2nd, 9th, 14th and 23rd session)

per 8 hour experimental period; i.e., a 120 min interpeak interval. Although

the difference in sleep stage 2 during the first 4 sessions between the REM

and NONREM awakenings was large (31% vs. 0%, 25% vs. 8.3%, 24% vs. 5% and

19% vs. 6.9%), this difference was due to large amounts of sleep stage 2

in 2 subjects only. Fig. 4 (lower pannel) presents the average curve for stage 2
for the evening experiments. It clearly resemble the average curve for stage 1.

Spectral analysis

Fig. 6 presents the average spectra for stage 1 for the morning

and afternoon time series. In agreement with the visual impressions the

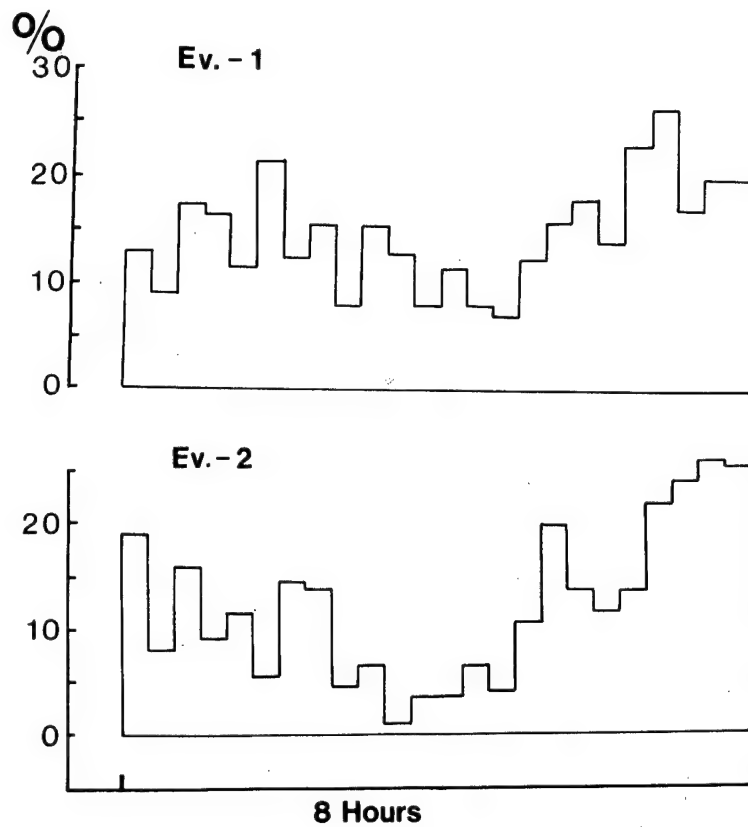afternoon spectra peaked at 3.6-7.2 cycles/day, corresponding to a

Fig. 4 Percentages of sleep stage 1 (Ev-1) and sleep stage 2 (Ev -2) for the evening experiments.
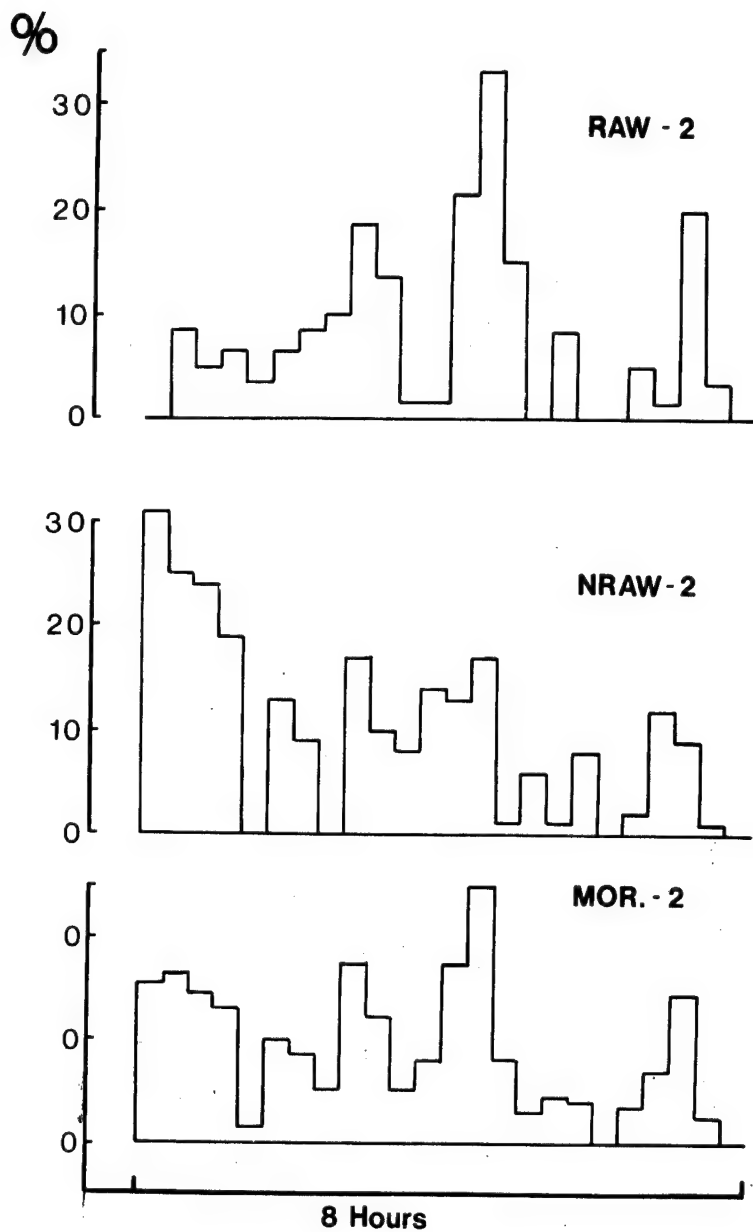
Fig. 5 A, B, and C. Percentages of sleep stage 2 for REM awakening, NONREM awakening and all mornings.
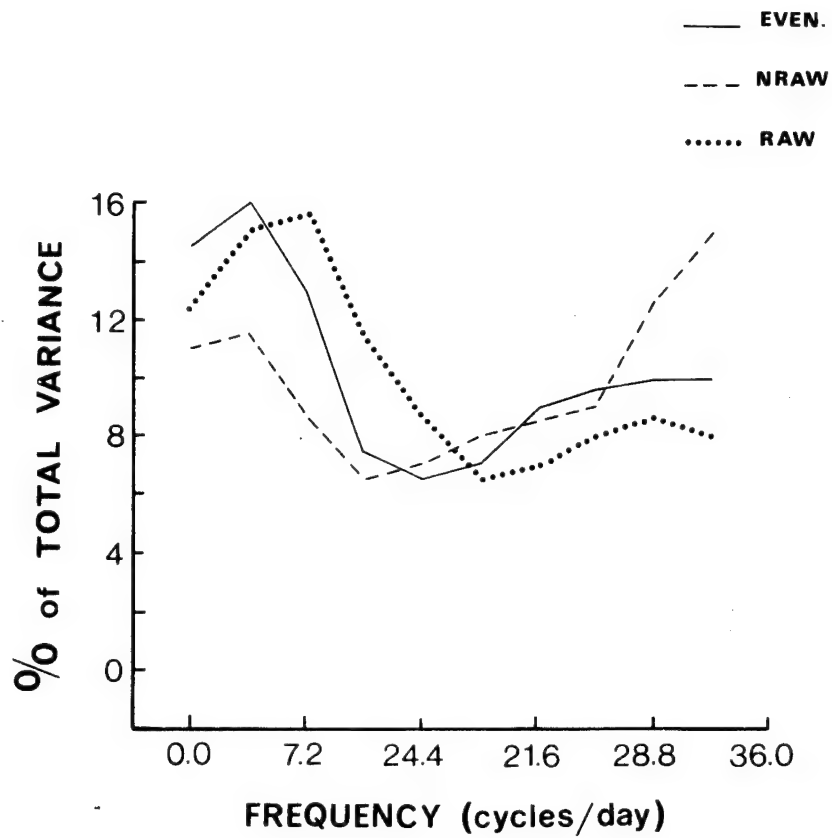
Fig 6. Average spectra for stage 1 for morning
(NRAW and RAW) and the evening experiments (EVEN).

periodicity of approximately 4-6 hours. The average spectra for the post REM experiments peaked at 7.2-10.8 cycles/day and at 25.2 cycles/day, corresponding to periodicities of approximately 1.5-3 hours and 1 hour. Similarly the average spectra for the post NONREM experiments peaked at 21.6 cycles/day and at 32.4 cycles/day, again indicating the existence of periodicities of approximately 1.5-1 h.

Summary

Several general conclusions can be derived from the wealth of the experimental data.

1) In 6 out of the 8 subjects there were differential effects of the awakening from REM and NONREM sleep on the immediate amounts of sleep stage 1 and 2, which persisted for approximately 90 min after the awakening. Afterwards, the pattern of sleep stages 1 and 2 appeared remarkably similar, suggesting possible anchoring of the diurnal sleepiness patterns in the time of awakening from sleep regardless of the sleep stage.

2) There was an impressive difference between the morning and evening "sleepiness" structure, both for stage 1 and for stage 2. Morning "sleepiness" was episodic while the afternoon pattern was quadratic, without any indication for the existence of fast frequencies. The morning quadratic pattern, albeit less prominent, was also evident in stage 1.

Rhythms in Performance - Dot Localization

Table 1 presents the average deviations of localization averaged across the four 8-hour testing periods (two afternoon-evening periods, and two morning, post-REM and post-NONREM testing periods) for group 1 and group 2. Performance was remarkably stable across the four testing

Table 1

Average localization errors for each group.

	Ev-1	Ev-2	RAW	NRAW	$\bar{x}$
	2.92	2.77	2.66	2.95	2.82
20 min Group	1.85	1.84	1.90	1.90	1.87
	2.0	2.13	2.03	2.39	2.14
	2.65	2.94	2.84	2.74	2.79
	3.24	3.62	3.58	3.70	3.53
10 min Group	2.21	1.81	1.92	2.28	2.06
	2.26	2.23	2.38	2.22	2.27
	2.31	2.72	2.18	2.48	2.42
$\bar{x}$	2.43	2.51	2.44	2.58	2.49

periods with large individual differences. Plotting the deviations against time revealed striking rhythmicities, particularly in group 1. Fig. 7 displays the average post-REM and post-NONREM performance curves of group 1.

Spectral Analysis of Group 1

Clear high amplitude ultradian rhythmicities were evident during the morning and evening testing periods. The overall average deviations were 2.35±0.5 mm and 2.42±0.52 mm for the afternoon testing periods and 2.36±0.46 mm and 2.5±0.46 mm for the post-REM and post-NONREM testings, respectively. Average 10 frequency variance spectra for the afternoon-evening and post-awakening time series revealed distinct spectral peaks at the same frequency of 21.6 cycles/day (corresponding to a periodicity of approximately 70 min/cycle. The average spectral peaks accounted for 15%-20% of the total spectral variance.

Spectral Analysis of Group 2

In spite of the fact that this group had twice the number of trials than group 1, 48 instead of 24, the overall average deviations were similar to Group 1: 2.5±0.49 mm and 2.59±0.78 mm for the afternoon-evening testings and 2.51±0.75 mm and 2.60±0.7 mm for the post-REM and post-NONREM experiments, respectively. In contrast to the results of Group 1, however, when the 48-point time series were analyzed, ultradian rhythms were considerably less evident. Although the three average spectra peaked at the same spectral frequency of 36 cycles/day (corresponding to periodicity of approximately 40 min/cycle) the average peaks accounted for about 13%-11% of the total spectral variance.

Figure 7: Average post-awakening rhythms in localization performance for Group 1 (N=4). Note that the rhythms are generally in phase throughout the 8 hour period.
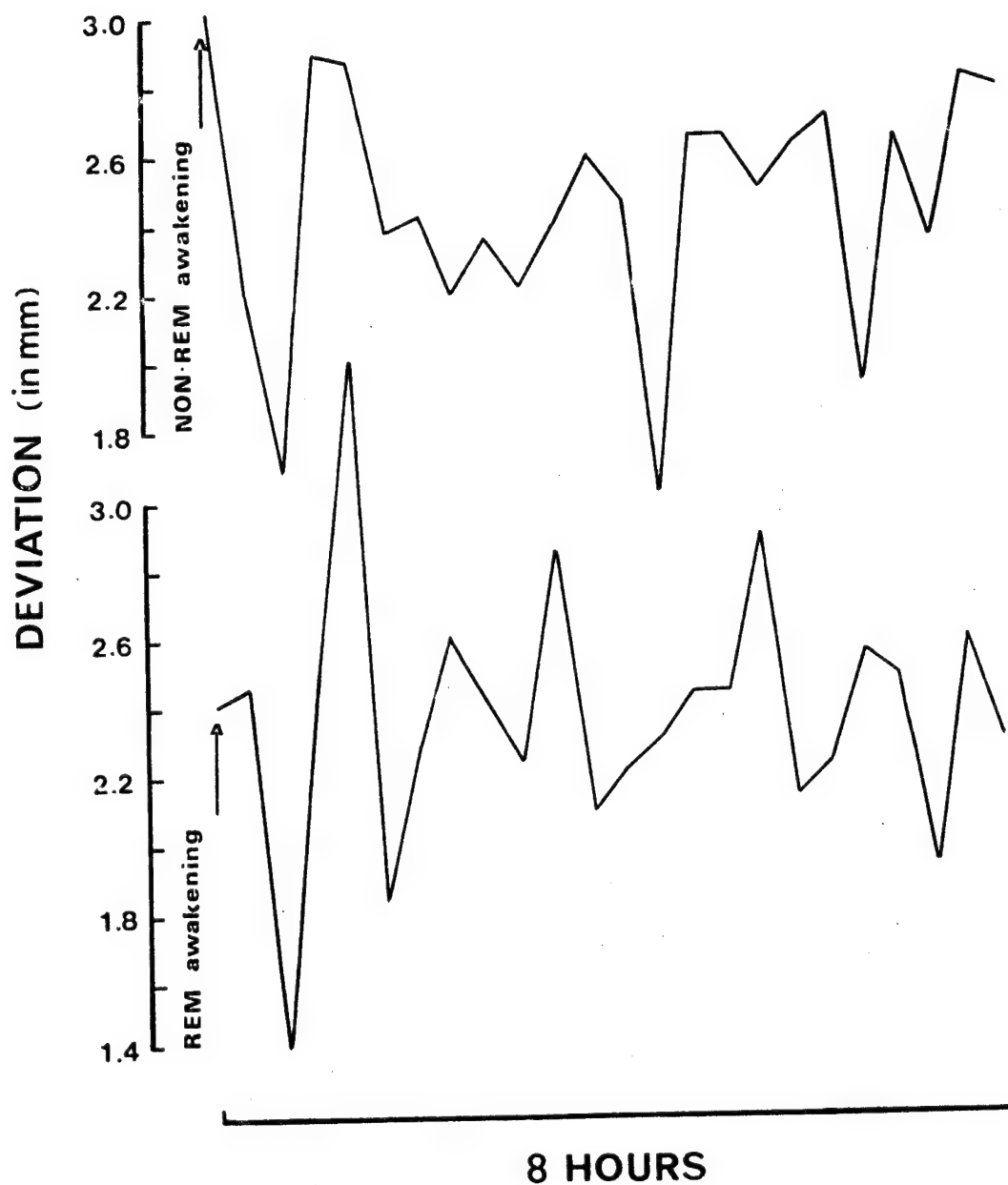
Phase Relationship Between the Post-REM and Post-NONREM Localization Performance

Pearson product moment correlation and cross spectral phase angle differences were computed between the post-REM and post-NONREM time series of localization performance. If indeed waking rhythms in performance are continuous with the sleep cycles, then reciprocal relationships are expected between the post-REM and post-NONREM rhythms.

In sharp contrast to the expected reciprocal relationship between the post-REM and post-NONREM rhythms, both Pearson product moment correlation coefficients and cross spectral phase angle analysis showed consistent in-phase relationship. All correlation coefficients were positive, and the average correlation was significantly greater than zero ($r=.23\pm.18$, $p < .02$). The average cross spectral phase angle difference (calculated at 21.6 c/day for Group 1 and at 36 c/day for Group 2) was $3^{\circ} \pm 40^{\circ}$ and the Rayleigh test (Batschelet, 1965) which tests phase consistency was significant ($p < .05$). The synchronization between the post-REM and post-NONREM rhythms is further exemplified in Fig.7.

Relationship between "sleepiness" measures and localization performance

None of the pearson product moment correlation coefficients between localization performance and percent stage 1 attained statistical significance. The average correlation for group 1, based on all 4 experiments of every subject, was $.02\pm.17$. For group 2, the average correlations were $-.09\pm.19$ and $-.02\pm.20$ for localizations performed before and after the 20 min sleep attempts, respectively.

Linear Positioning

Group 1

Since our previous studies demonstrated that knowledge of results suppresses the ultradian rhythmicity, linear positioning performance was analyzed only for trials without knowledge of results (NKR condition). Sessions just before the 20 min "sleep attempts" and immediately after the "sleep attempts" were analyzed separately.

NKR after sleep - All average 10 frequency spectra had at least one ultradian peak (underlined): average afternoon spectra peaked at three frequencies: 3.6 c/d, 18 c/d and 32.4 c/d, average post-REM spectra peaked at 3.6 c/d and 21.6 c/d and the post-NONREM spectra peaked at 14.4 c/d.

NKR before sleep - Similarly all spectra had at least one ultradian peak; average afternoon spectra peaked at 14.4 c/d, and 32.4 c/d, average post-REM spectra peaked at 14.4 c/d, 7.2 c/d and 25.2 c/d and the average post-NONREM spectra peaked at 3.6 c/d, 18 c/d and 32.4 c/d.

Group 2

Average spectra for the afternoon time series peaked at 10.8 c/d, and at 14.4 c/d, and at 28.8 c/d and at 7.2 c/d for the post-REM time series and for the post-NONREM time series, respectively.

Forty-eight-point time series

Linear positioning data of subjects in Group 1 were reanalyzed using 48-point time series which could be formed by combining the before and after sleep trials.

Ten frequency spectra were calculated for each of the 4 time series constructed from the two afternoon and two morning time series of each

subject. Then average spectra were calculated for each condition.

Confirming the low resolution analysis the average spectra for the afternoon time series for the NKR condition peaked at 14.4 c/d.

Spectra for the post-NONREM time series also peaked at 14.4 c/d and 50.4 c/d, but there was no distinct spectral peak in the average spectra for the post-REM time series. That is, in two of the 3 experimental conditions, the more refined analysis using the 48-point time series confirmed the more robust analysis that was based on 24-point time series.

Relationship between "sleepiness" measures and positioning performance

In group 1, only one out of the sixteen possible correlations between percent sleep stage 1 and positioning performance (4 correlation coefficients, one for each of the 4 experiments of each subject) was significant (r=.41, p < .05). The average correlation was -.06±.18. In group 2, there were 3 significant correlations with performance immediately after the "sleep attempts" (r=.5, .62, .53) and two significant correlations for performance before the "sleep attempts" (r=.57, .4); the average correlations were .1±.3 and .06±.24, respectively. Thus all in all, there were 6 significantly positive correlations between percent sleep stage 1 and positioning perfor- mance. It should be indicated, however, that linear correlation analysis is of limited value in the investigation of phase relationships between time series. Cross correlation analysis, cross spectral analysis and coherence spectra are required, in order to reveal the covariations of rhythms in performance and in physiologic indices of arousal, or sleepiness. Such analysis is currently being performed in our laboratory.

Discussion

The present results confirm our previous findings on the existence of ultradian rhythms in "sleepiness" but further demonstrated that there is a different temporal structure for "sleepiness" during the morning and afternoon hours, and that the timing of the diurnal sleepiness structure is not anchored in the sleep stage cycles. As was discussed in the introduction, Kleitman's BRAC model, which predicted orderly fluctuations in arousal during the waking day, assumed a continuity between the sleep REM-NONREM cycles and the waking portion of the BRAC. According to this model, the diurnal sleepiness rhythm is "locked" in the sleep stage rhythms, and interrupting sleep at either a REM, or NONREM stage, would result in diurnal rhythms reciprocal in phase to each other. Our present results clearly contradict this assumption, and favour a different phase relationship between the sleep stage cycles and the diurnal sleepiness rhythm. Besides a short-lasting differential post-awakening effect of increased sleepiness after awakening from NONREM sleep, which was evident in 6 out of the 8 subjects, post awakening REM and NONREM rhythms were generally synchronized with each other. One possible explanation for this synchronization is that the phases of the diurnal rhythms are anchored in the process of awakening from sleep, regardless of the particular sleep stage. That is, the transition from sleep to awake triggers a rhythmic, or "near rhythmic" process of alternating periods of increased and decreased "sleepiness". Such a mechanism is analogous to the role of the transition from awake to sleep on the REM-NONREM cycles. When retiring at habitual sleep time (2200-2400), the first REM period generally appears 60 to 140 min after sleep onset (the transition from awake to sleep) with an average latency of about 90 min. In our experiment, in spite of the initial post

awakening differences in the amount of stage 1 and stage 2, the first
sleepiness peak appeared about 100 min after the awakening. This may
indicate that as sleep onset resets the sleep stage cycles, the awakening
from sleep resets the diurnal sleepiness rhythms.

The results of the afternoon time series complicated the picture even
further. First, the temporal structure of the fluctuations in sleepiness
during the afternoon experiments was drastically different than the structure
in the morning experiments. Instead of episodic fluctuations, with peaks
recurring about every 80 to 100 min, the variations in sleepiness were
much slower with a predominant quadratic trend which was common to all
subjects. These differences are even more impressive in light of the
lack of differences in the total amounts of sleep stages 1 and 2 between
the morning and afternoon experiments.

The nonstationarity of the sleepiness rhythms agree with previous
results on nonstationarity in waking ultradian rhythms (Lavie, 1977),
which demonstrated slowing down of waking rhythms in perceptual processes
toward the afternoon-evening hours. Without going into great detail about
the nature of this nonstationarity, it should be mentioned that similar
nonstationarity exists in the periodicity and latency of the REM-NONREM
sleep stage rhythms, the nocturnal analogous of the diurnal "sleepiness"
rhythms; and that this nonstationarity has been linked recently with the
circadian temperature rhythms.

It is yet to be determined, however, if the quadratic trend reflects
a slow sleepiness rhythm of about 4-5 hours which predominates during
afternoon-evening hours, or reflects different phenomena such as
"primacy" and "recency" effects. It is also possible that the first
sleepiness peak represents part of the "post-lunch dip" and the second

peak the accumulated fatigue and boredom associated with the experimental design. In our previous experiments, we demonstrated (Lavie & Scherson, 1981) that the ultradian 80-100 min rhythms in sleepiness is modified under sleep deprivation conditions towards a much slower 4-5h rhythm. We therefore tend to believe that the 4-5h rhythmicity reflects a "true" endogenous rhythm which manifested in specific portions of the circadian cycle, or under increased need for sleep. If this assumption is correct then it may shed a new light on the question of the role of "restorative naps" following sleep deprivation, which also has some immediate practical implications.

The results of the performance part of the study confirmed our previous results regarding the rhythmicity in motor behavior. However, the results regarding the possible rhythmicity in cognitive asymmetry, first described in Science by Klein and Armitage (1979), are probably a statistical artifact. The fact that different periodicities (40 min and 80 min) were obtained when performance was sampled every 10 or 20 min, suggests that the ultradian rhythms were due to inappropriate sampling interval, which was too short to detect the true rhythmicity in the data. It is possible then that there are fluctuations in perceptual performance related to right hemispheric performance, but they are much faster than the predicted 80-100 min rhythms.

The phase relationships between the physiologic indices of arousal and linear positioning performance is still an open issue. Although there were only few significant correlations between the two rhythmic processes, the linear correlation analysis is obviously inappropriate for phase relationship analysis. Cross spectral phase angle analysis is currently being performed in our laboratory to further verify this interesting issue.

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